Project ID: EEMS034
Multi-Modal Freight Pillar

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Optimization of Intra-City Freight Movement and New Delivery Methods

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2019 Vehicle Technologies Office Annual Merit Review
June 12, 2019

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

Advanced Fueling Infrastructure

Connected & Automated Vehicles

Urban Science

SMART MOBILITY LAB

CONSORTIUM

7 labs, 30+ projects, 65 researchers,
$34M* over 3 years.

Mobility Decision Science

Multi-Modal Transport

*Based on anticipated funding

OVERVIEW

Timeline

- Project start date: October 2016
- Project end date: September 2019
- Percent complete: 80%

Budget

- Total project funding — $1,540,000
- DOE share: 100%
- Funding for FY 2019 – $745,000

Barriers and Technical Targets

- Barriers —Complexity of large-scale integrated transportation networks
- Technical Targets — Determining the value and productivity derived from new freight modes and technologies

Partners

- Oak Ridge National Laboratory
- Idaho National Laboratory
- Argonne National Laboratory
- National Renewable Energy Laboratory
- United Parcel Service
- Chicago Metropolitan Agency for Planning

OVERVIEW

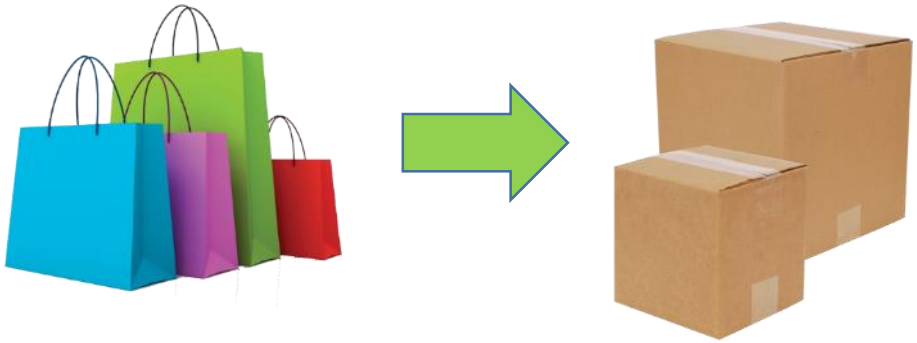
- **Overall Objective**: Evaluate energy-saving potential of new intra-city freight delivery methods by:
  - Estimating parcel freight delivery demand
  - Establishing freight delivery tour locations and routes
  - Modeling baseline and alternative scenarios using innovative modes and methods
  - Calculating energy consumption for each scenario

- **Focused Efforts**: Collaborate with Argonne National Laboratory and support further development of freight agents within POLARIS by:
  - Estimating freight deliveries that are replacing passenger vehicle shopping trips within Chicago
  - Modeling freight origin facilities
  - Estimate and model delivery tours to provide baseline to POLARIS
  - Compare energy consumption estimates for alternative scenarios with baseline

RELEVANCE

E-Commerce

- E-commerce is quickly replacing traditional consumer shopping trips



Behavior: Shopping to Shipping

Urban Pressure

- Congestion levels in metropolitan areas are a growing problem
- Increased vehicular traffic, failing infrastructure, and growing populations within urban areas are leading to problems for delivery vehicles (trucks) by:
  - Increasing VMT
  - Increasing time and cost of delivering goods
  - Preventing adequate parking and temporary curb space

RELEVANCE

New Technology

- New transportation modes are changing how people and goods move (TNCs, scooters, robots, drones), but they need further evaluation

- Government and industry can benefit from large-scale (mesoscopic) models of transportation networks within cities to better understand interactions, especially with regards to freight and passenger movement

- This work takes the aforementioned facts into consideration by:
  - Modeling freight and passenger (current and predicted) movements within Chicago
  - Evaluates feasibility and energy-saving potential of new modes for delivering freight

MILESTONES

Milestone Name/Description	Criteria	End Date	Type
Q2 - Analyze consumer behavior data and existing passenger and freight movement data for Chicago and provide data set to Polaris.	Dataset estimates provided to Polaris	1/31/2019	Quarterly **COMPLETE**
Q3 - Characterize energy use for new freight technologies and incorporate micro-models based on the results **Using the modeled tour routes developed by integrating OD freight flows in POLARIS, develop micro-level/last-mile multi-modal scenarios and evaluate energy impacts**	Report on energy use and scenario results	3/30/2019	Quarterly
Q4 - Provide detailed data and analysis on intra-city freight movements (baseline and projected) for Chicago using delivery scenarios	Report on scenario results and baseline changes in energy.	9/30/2019	Annual

Approach

- **Investigate Technologies**
  - Work with partners to look at future delivery methods
  - Investigate new delivery modes
- **Gather Delivery Data**
  - Work with partners to understand delivery demands
- **Model scenarios**
  - Use advanced GIS tools to identify possible energy and business impacts
- **Expand to Regional Impacts**
  - Collaboration with POLARIS to model impacts for entire Chicago region

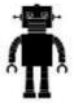
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Investigating Potential Delivery Technologies

- Vehicle Electrification

- Drone Delivery

- Lockers / Distribution points



- Automated Ground Delivery

- Small Vehicle Fleet (Network Delivery)

- Delivery on-demand

DELIVERY TECHNOLOGIES

Drone Delivery

- Key emerging technology
  - Quick delivery
  - Reduced congestion
  - Force Multiplier

- Characterization needed to understand how to best utilize drone options:
  - Understand energy requirements
  - Research on how package delivery impacts use and energy
  - Look at key elements driving costs

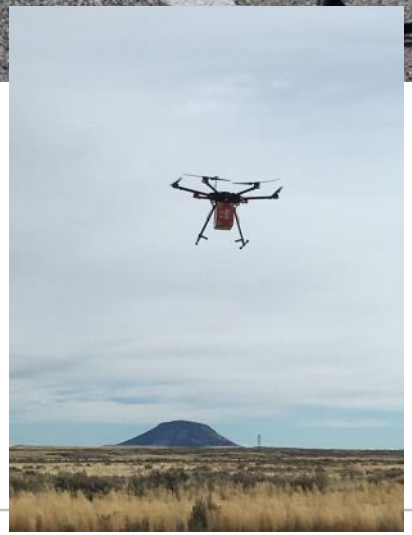
DRONE ENERGY CHARACTERIZATION

Heavy Weighted Drone Tests

- High Altitude:
  - November 2017
  - INL UAV Test Range
  - Altitude: 4885 ft Temp: 40 F
- Low Altitude:
  - March 2019
  - Miami, Florida
  - Altitude: 4 ft Temp: 70 F

Drone:

- Matrice 600 Pro
- Weight: 21 – 22 lbs
- Number of propellers: 6
- Max takeoff weight: 34 lbs
- Max speed: 40 mph



DRONE ENERGY CHARACTERIZATION

Flight Patterns:

- 50 Foot Lift – Hover - Drop
- 100 Foot Lift - Hover – Drop
- 1 Mile route at 100 feet
  - 6 turn box route
  - 30 mph flight speed
  - 17 mph in Idaho only

Package

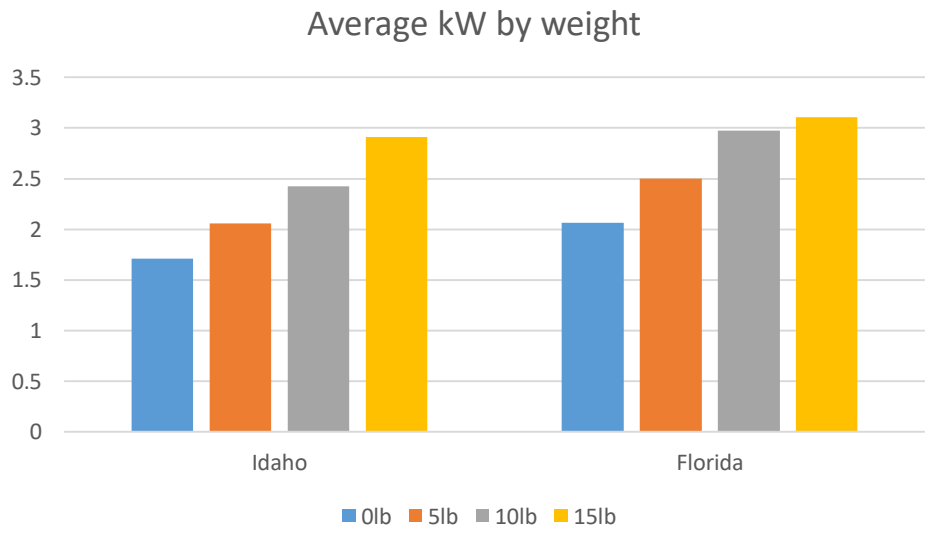
- Cheez-It container
- Weights:
  - 0 lbs
  - 5 lbs
  - 10 lbs
  - 15 lbs

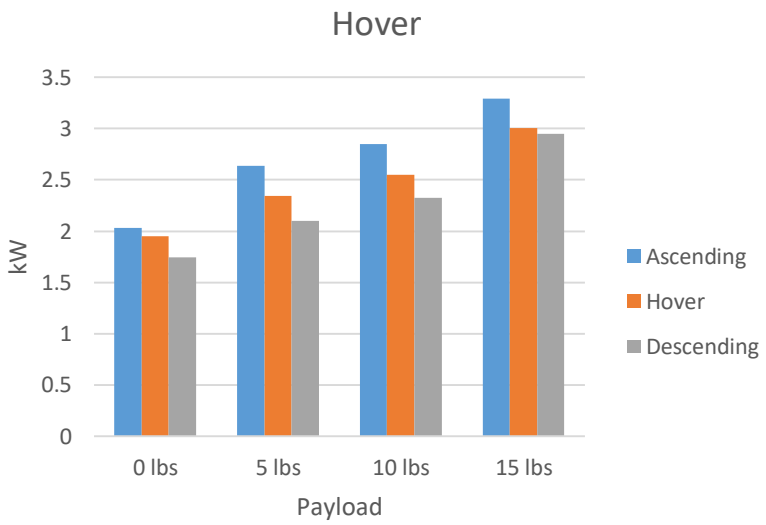
DRONE ENERGY CHARACTERIZATION

Analysis from motor logs - ongoing kW use during tests

Weight has significant impact on energy

Lower altitude / higher temps increase energy use





DRONE ENERGY CHARACTERIZATION

Light Weighted Drone Tests

- High Altitude:
  - December 2018
  - Utah
  - Altitude: 4760 ft
- Low Altitude:
  - December 2018
  - Miami, Florida
  - Altitude: 1 ft

Drone:

- Mavic Pro 2 Enterprise
- Weight: 1.9 lbs
- Number of propellers: 4
- Max takeoff weight: 2.4 lbs
- Max speed: 44 mph

Tests

- Hover
- 1 Mile Route
- 0 pounds
- .3 pound (5 oz)
- Currently only battery level results

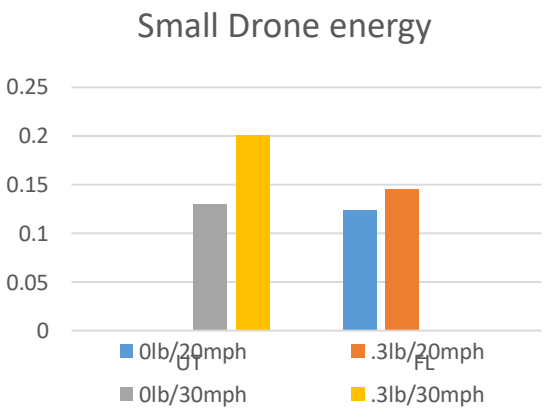
DRONE ENERGY CHARACTERIZATION

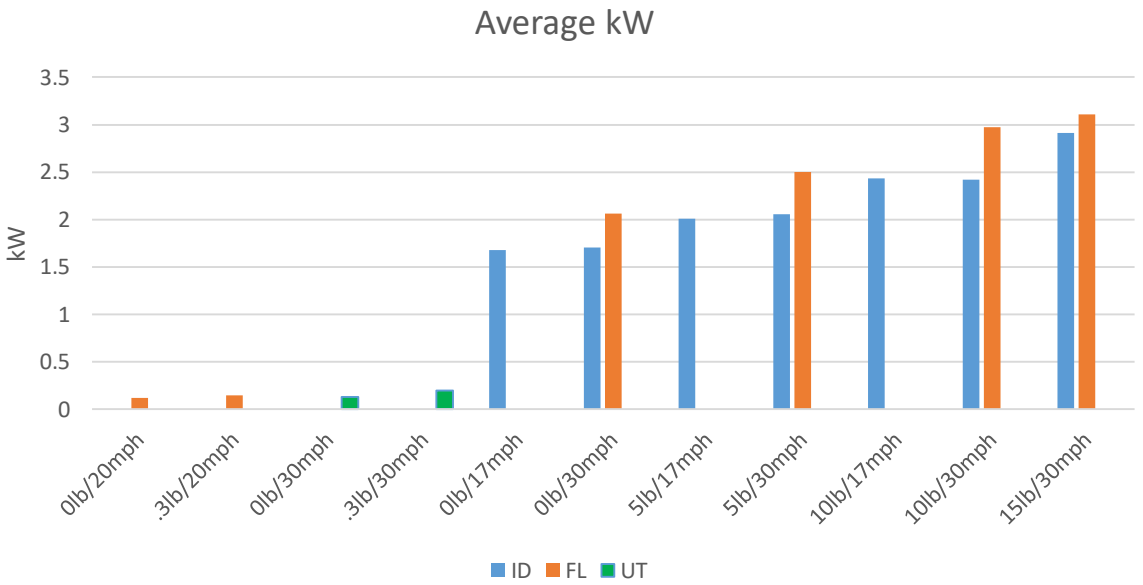
KW Use

Speed does not impact ongoing energy but takes longer to cover a mile

Smaller drones use significantly less energy

Weight provides significant increase

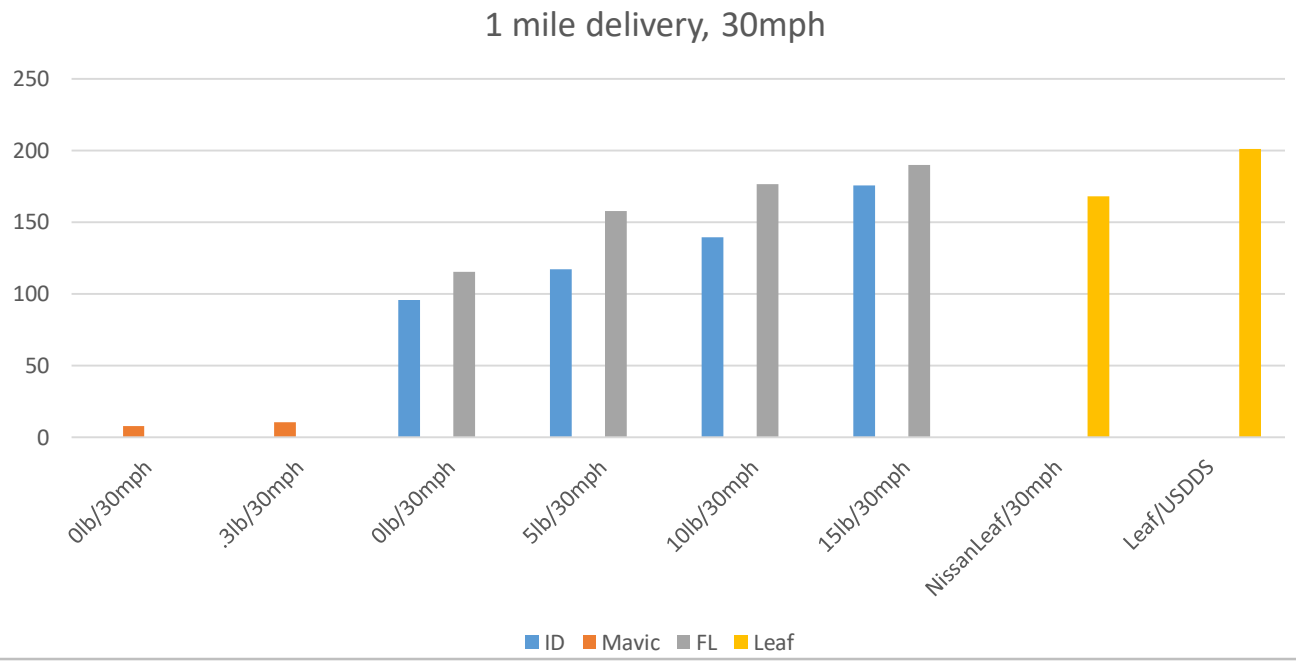




Drone Energy Characterization

1 Mile Delivery Results (from Motor logs)

- Faster speeds mean less time in air per mile and lower energy use
- Energy use comparable to passenger EV at single mile and high weights
- Smaller drones are better for very small weights



Energy Cost Implications

Battery impact

- Most Drone batteries specialized for light weight and high output. Can result in short life-cycle.
- For Matrice 600 Pro:
- 6 Batteries per flight
- Each battery ~$200
- Battery rated for 200 cycles
- Battery use:

  With 6 kg payload hover time: 16-18 minutes

- 100 feet – lift and descent = ~1 minute.
- 2 mile trip at 30 mph = 4 minute+
- 1 round trip delivery for 2 miles = 10 minutes.
  - Approximately 2 trips per battery charge
- Each battery rated for approximately 400 deliveries worst case.

- $1200 batteries / 400 deliveries of 12 pounds = ~ $3 per trip

Testing:

- Charge profile
- Discharge profile and conditions

DELIVERY TECHNOLOGIES

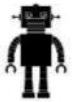
Drone Delivery

- Potential for improving delivery
- Less ground congestion
- Faster options
  - Wing operates at 80 mph

- Faster delivery is less energy
- Effective for smaller packages
- Time essential

- Costs and impacts still need study.

DELIVERY TECHNOLOGIES



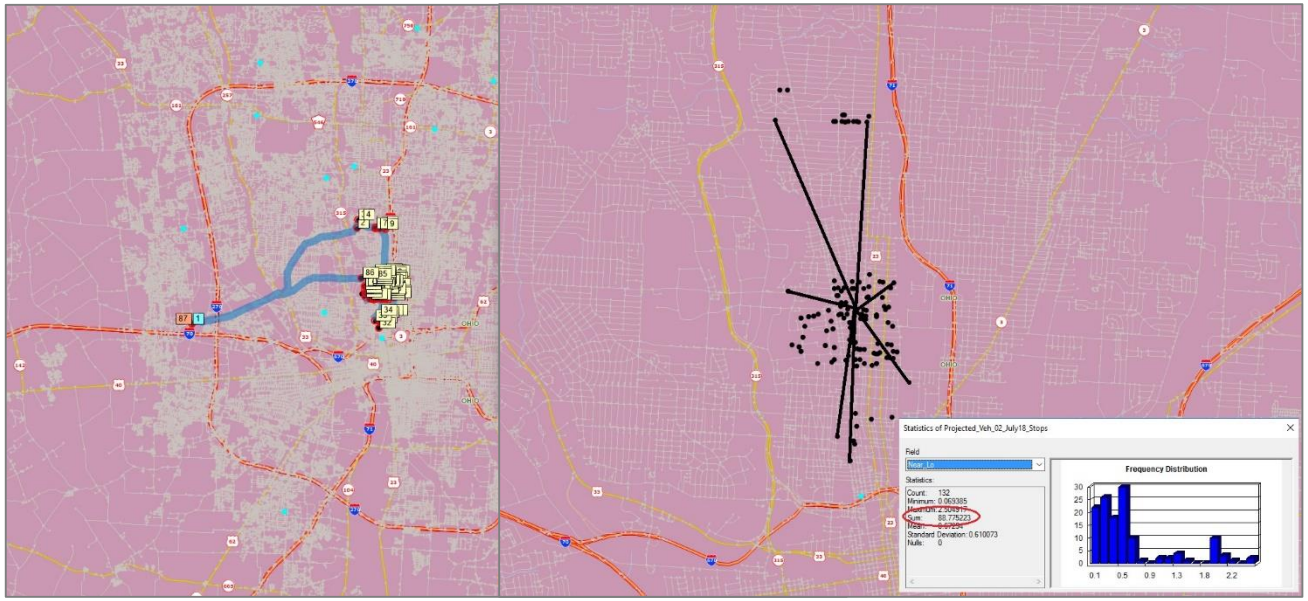
Automated Ground Delivery

- Key emerging technology
  - Last mile delivery technology
  - Heavier deliveries than drones
  - Force Multiplier / Potential for Reduced Cost

- Examples:
  - Nuro https://nuro.ai/
    - Automated on-road delivery
    - Electric Vehicle that is smaller than standard car
    - Delivery to curbside
    - Max 2 customers per trip (Currently)
    - Offering grocery delivery in Arizona
    - Delivery on roads within 5 mile radius
  - Fed-EX Same-Day Bot https://thefuturefedex.com/
    - Smaller robot for last 50 feet delivery
    - Side-walk accessible
    - Delivery to door
    - Good for urban environment
    - Starting testing this summer

FY 18 OVERVIEW

Scenario	Total Daily Fleet Energy Usage kwh	Reduction in Energy Usage from Baseline
Class 6 Truck	2,450	N/A
EV Class 6 Truck	570	77%
EV Delivery Van (eNV200)	1,482	40%
Class 6 Truck/lockers	1,273	48%
EV Class 6 Truck/lockers	295	88%
Drone	2,128	13%
EV Passenger Car (Nissan Leaf)	1,349	45%



#SMART COLUMBUS

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U.S. DEPARTMENT OF ENERGY SMARTMOBILITY

Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · OAK RIDGE National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Overview of Chicago Modeling Efforts

- Used UPS delivery demand estimation model and Census-level data from CMAP to estimate UPS parcel deliveries in the Chicago MSA at the TAZ-level (destinations)
- Located UPS depots and stores, and potential locker locations (origins)
- Provided O-D pairs and estimates to ANL to be used as input for POLARIS to represent displaced passenger vehicle shopping trips
- ANL selected three tours to calculate baseline energy usage in POLARIS
- Using TransCAD and ArcGIS, various alternative scenarios were developed for the three, selected tours
- Energy usage for the scenarios were calculated to compare with baseline estimates in POLARIS

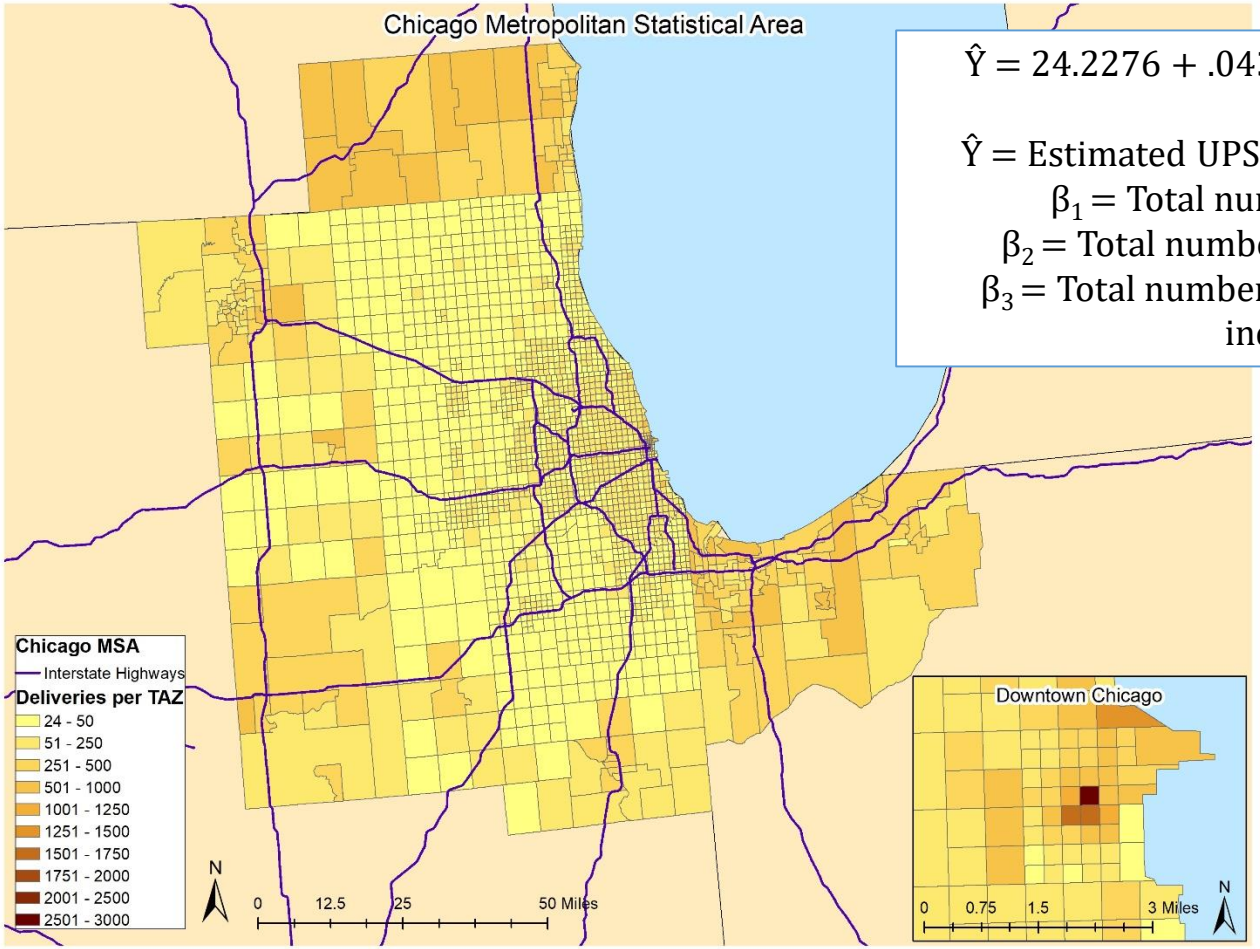
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- Developed TAZ-level UPS delivery demand estimation model for Chicago MSA using:
  - Census-level data from Chicago Metropolitan Agency for Planning (CMAP)
- Provided TAZ-level UPS delivery estimates to ANL
- Developed GIS layers necessary for analysis:
  - Created randomly-dispersed point layer in ArcGIS based on TAZ-level estimates of deliveries
  - Plotted all locations of UPS depot hubs and customer service centers in Chicago MSA to provide as tour origins to ANL and POLARIS
  - Assigned service areas to each of the 15 depots (manually divided delivery point layer into 15 groups)
  - Used Python and a sorting algorithm, inherent to ArcGIS to create tours of approximately 120 points from the service areas
  - Used Python to create CSV file containing approximately 24,000 tours to provide as input to POLARIS representing destinations
- ANL chose three tours to be used as scenario examples; as previously done in Columbus, three tours were chosen to represent varying development densities and levels of road network connectivity (an urban tour, suburban tour, and a tour near the central business district – CBD)

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- Modeled tour scenarios in the GIS:
  - Loaded tours into TransCAD, along with the UPS depots; the shortest path function was used to determine the route distance
  - UPS store locations across Cook and Dupage counties were obtained and a point file was created in ArcGIS
  - UPS store location point file was used to determine the closest UPS stores relative to the tours; these stores were used in-conjunction with the tours in TransCAD to find the optimal route distance
  - Tour files were loaded into ArcGIS and the Means Center function, which uses Moran's I to locate the centroid within a cluster of points was used to determine the location for a locker facility and a parking location to launch drones
  - Points were loaded into TransCAD, to find the optimal route distance from the depot and the UPS stores to the locker/drone launching location
  - The latitude and longitude for the locker locations were obtained and located in Google Streetmap to find the actual locations and determine feasibility
  - The Near Analysis function in ArcGIS was used to determine the Euclidean (straight-line) distance from the locker location to all points to represent the drone flightpath distance
  - The locker locations were also used in TransCAD, along with the tour points, to determine distance to the lockers, which will also represent launching locations/paths for robots to make deliveries
- After obtaining all distances from TransCAD and ArcGIS, energy calculations were performed, compared with estimates for the baseline from POLARIS

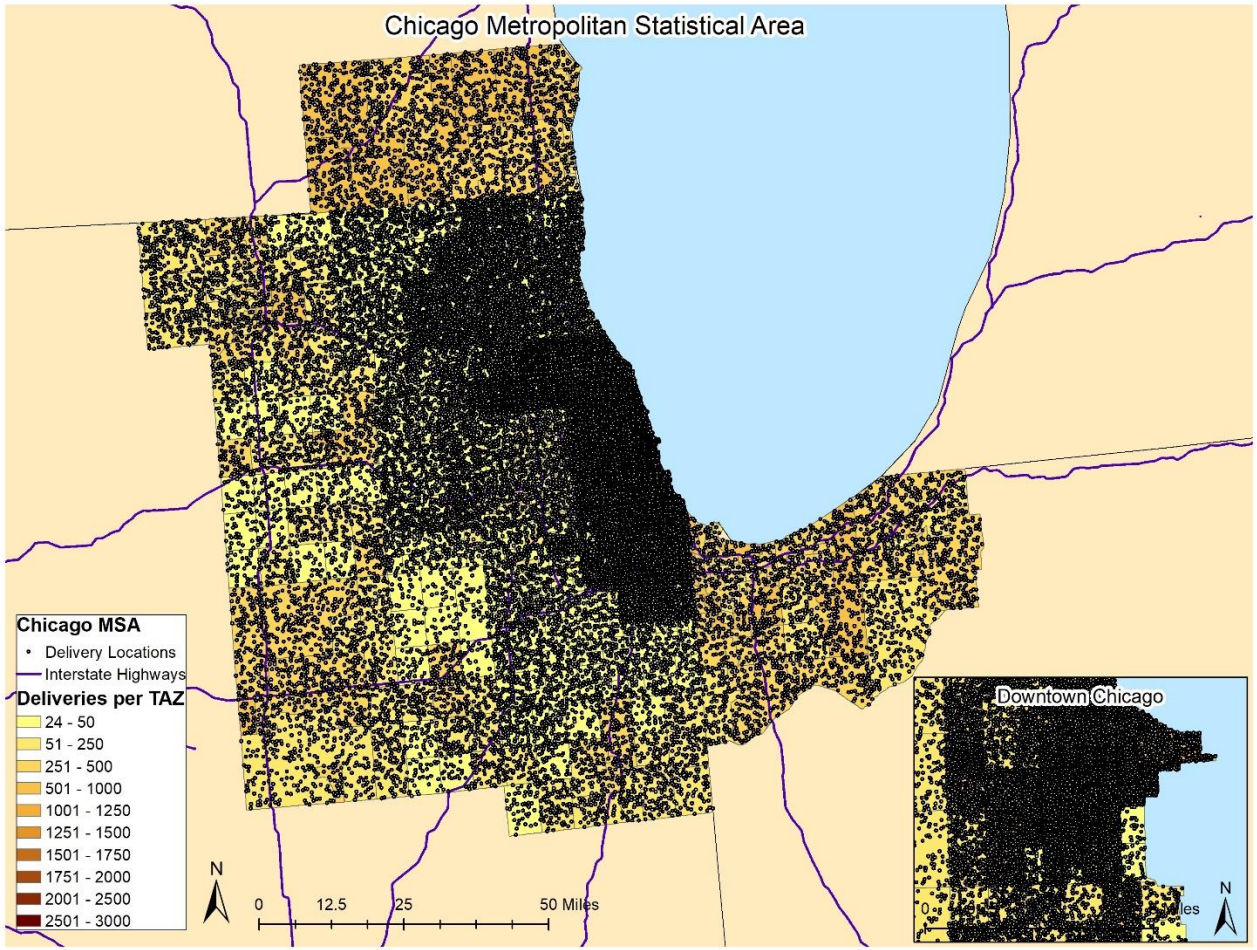
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
TAZ-Level Delivery Estimates



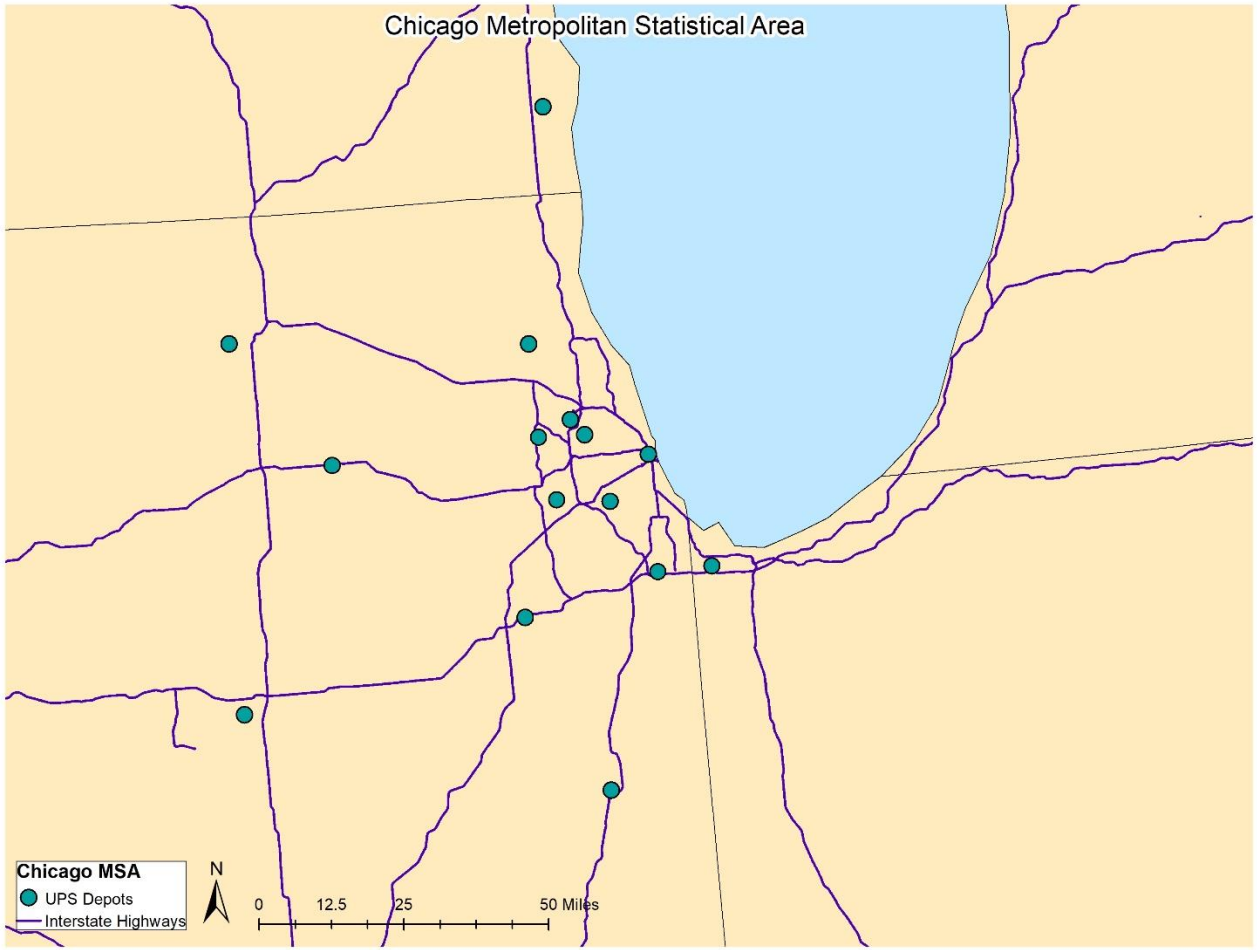
$$\hat{Y} = 24.2276 + .043127\beta_1 + .028473\beta_2 + .033524\beta_3$$

$\hat{Y}$ = Estimated UPS parcel deliveries per TAZ per day
β_1 = Total number of households per TAZ
β_2 = Total number of retail service jobs per TAZ
β_3 = Total number of all jobs (retail service, office, industrial) per TAZ

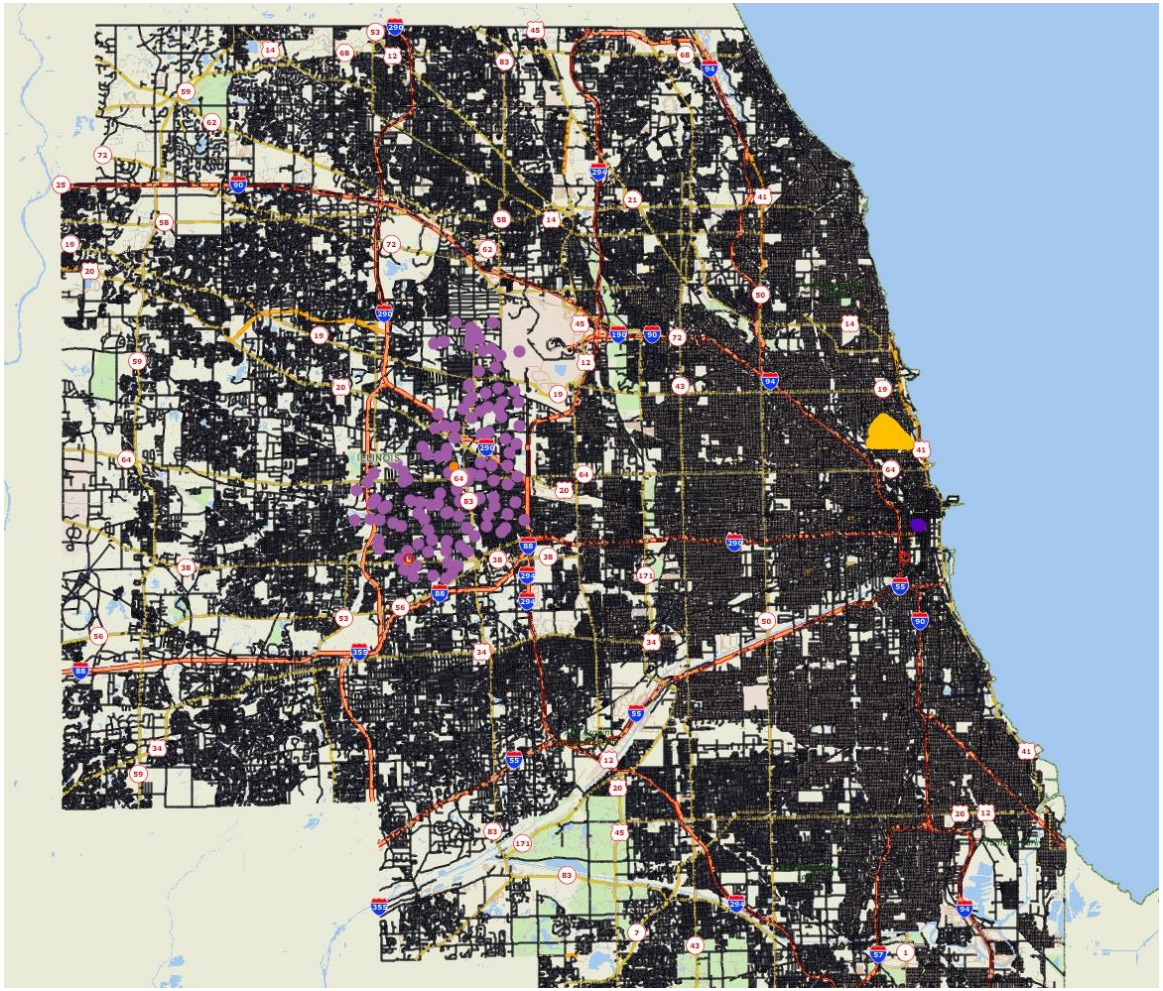
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Delivery Locations



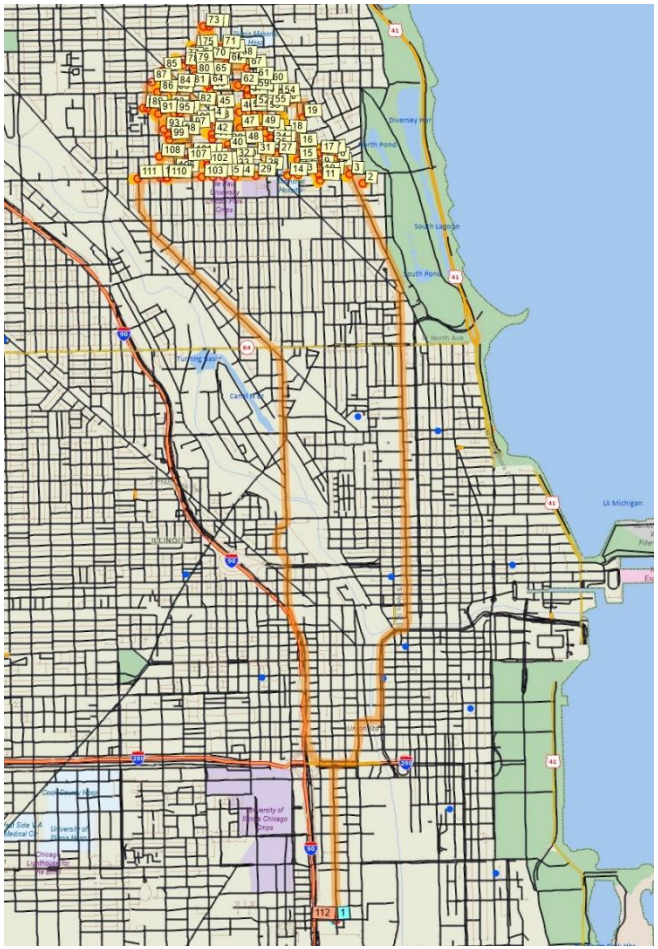
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
UPS Depot Locations

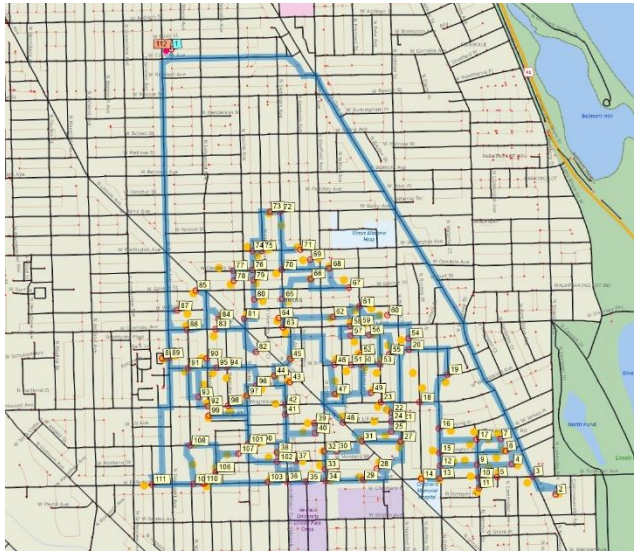


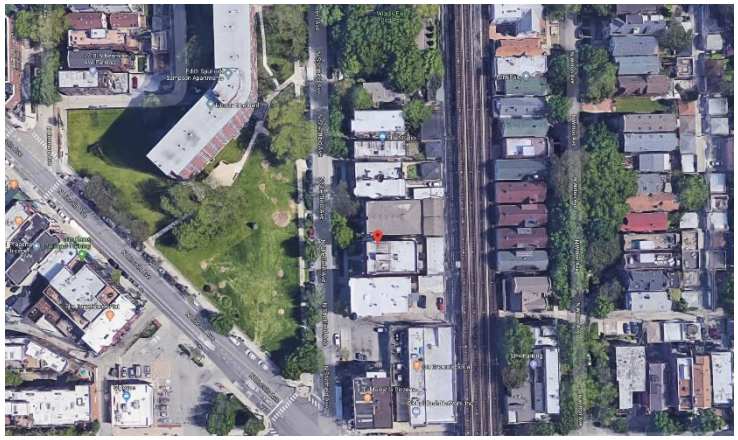
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Chicago Tour Locations



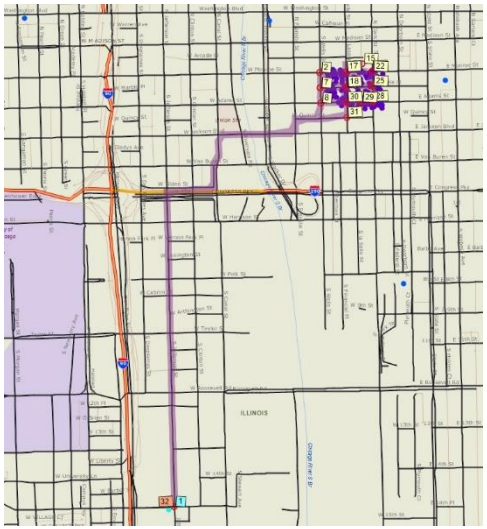
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Jefferson 2880 (Urban) Tour

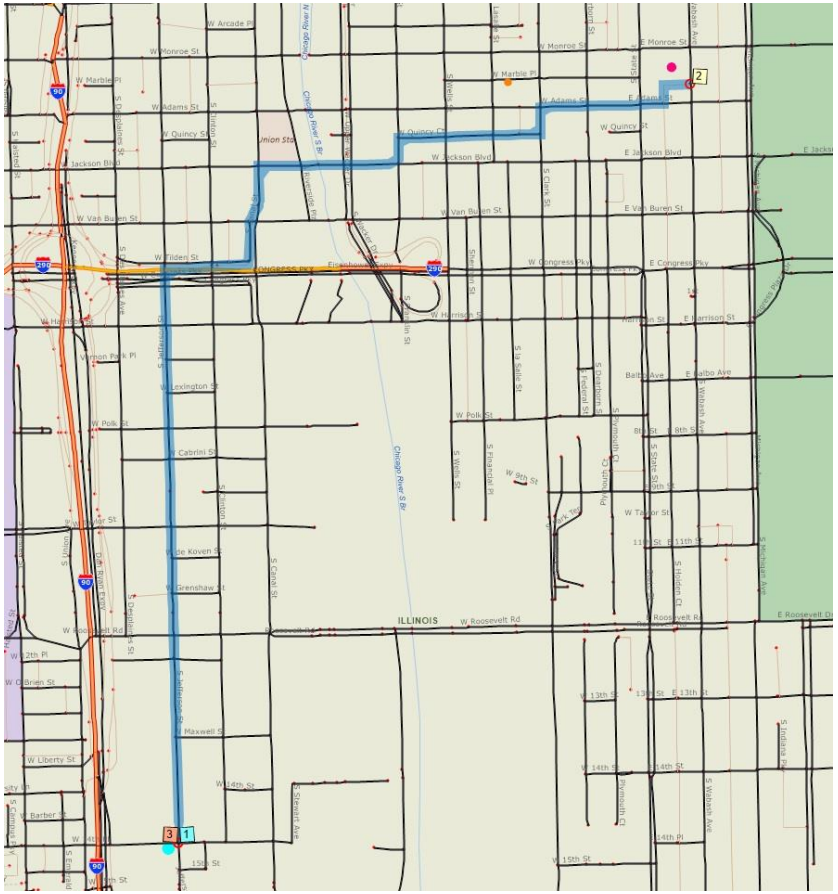




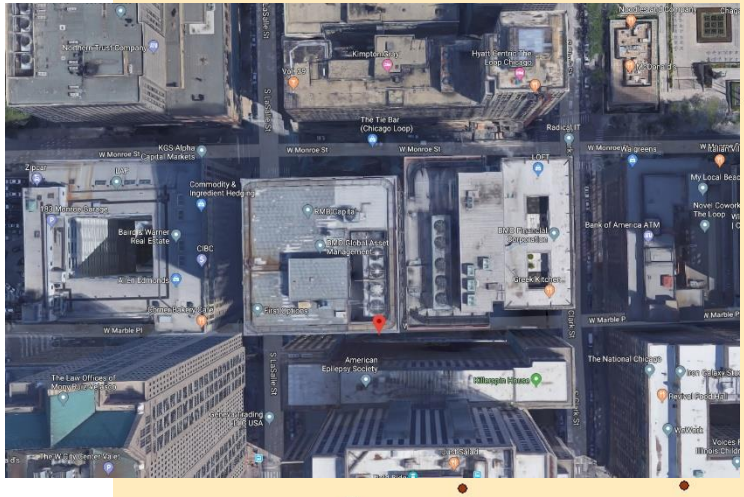


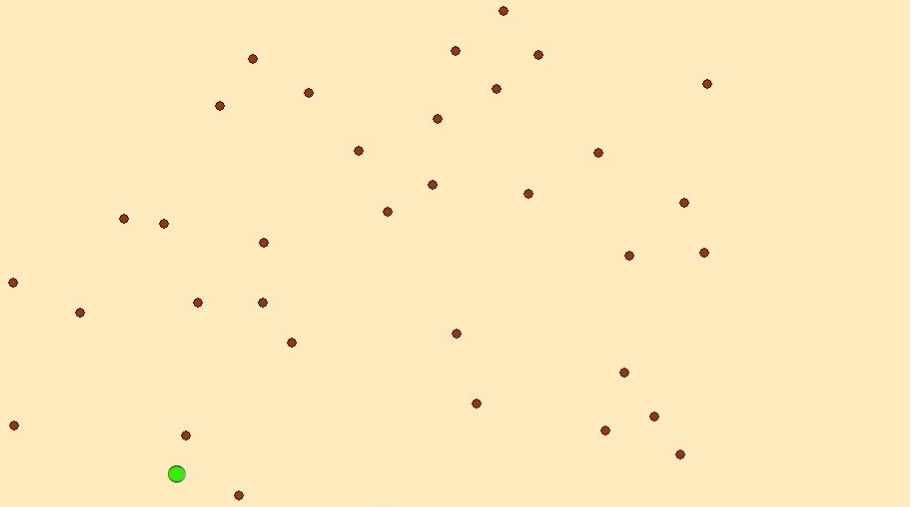
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Jefferson 4440 (Urban - CBD) Tour

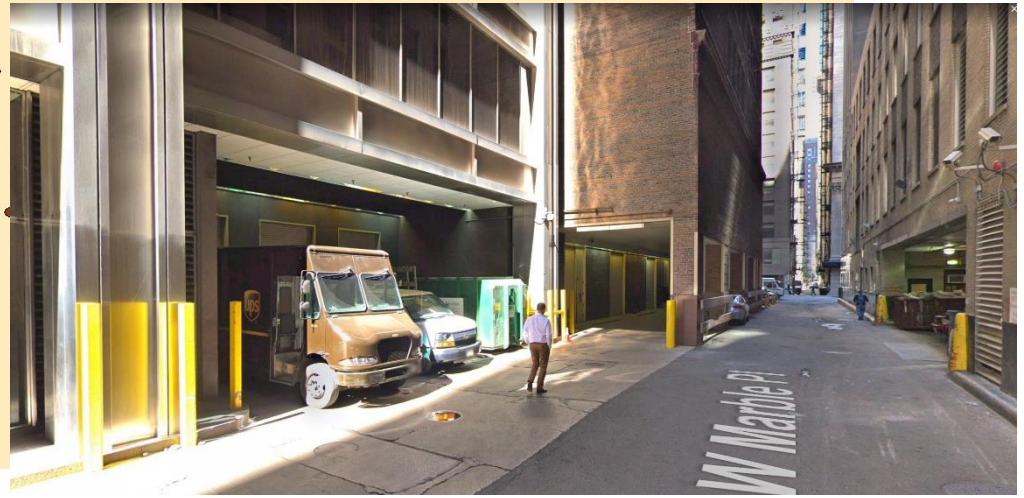




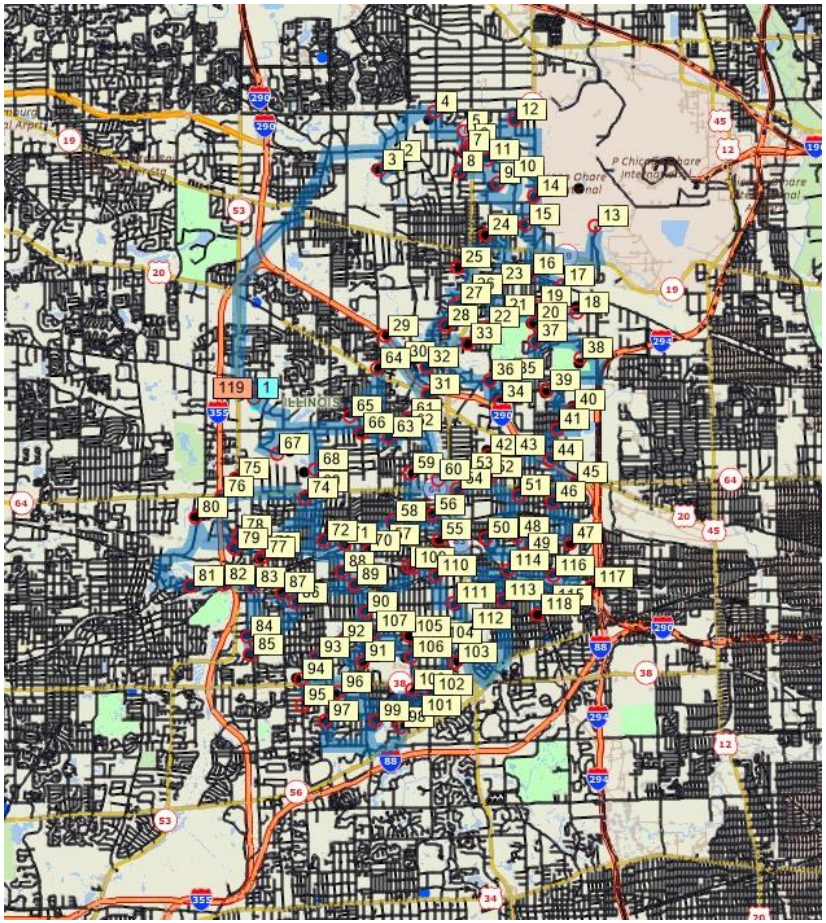
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Jefferson 4440 Downtown (CBD) Locker Location

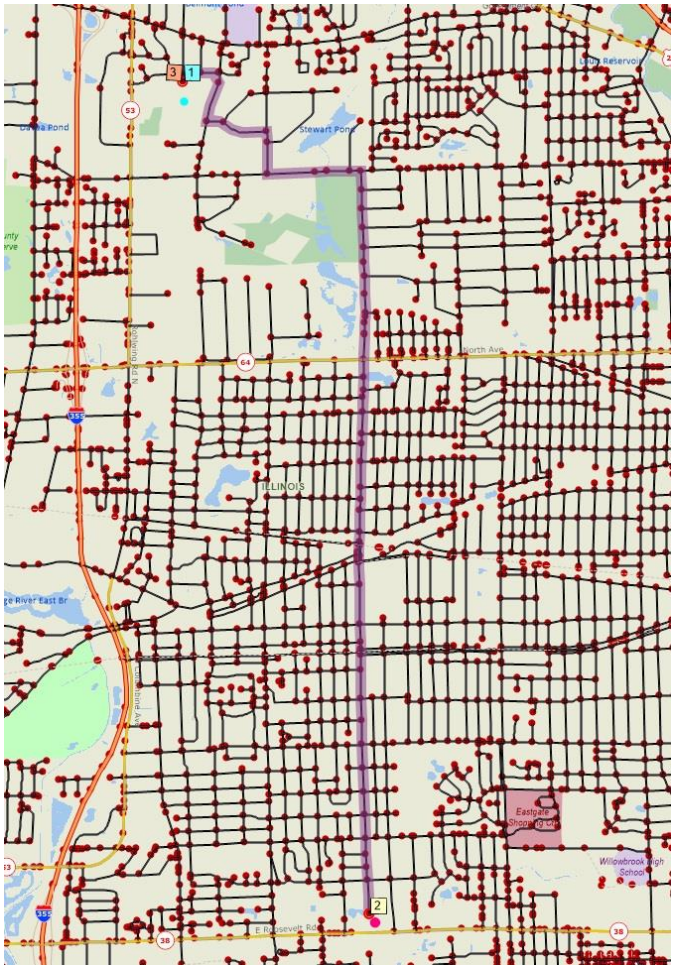




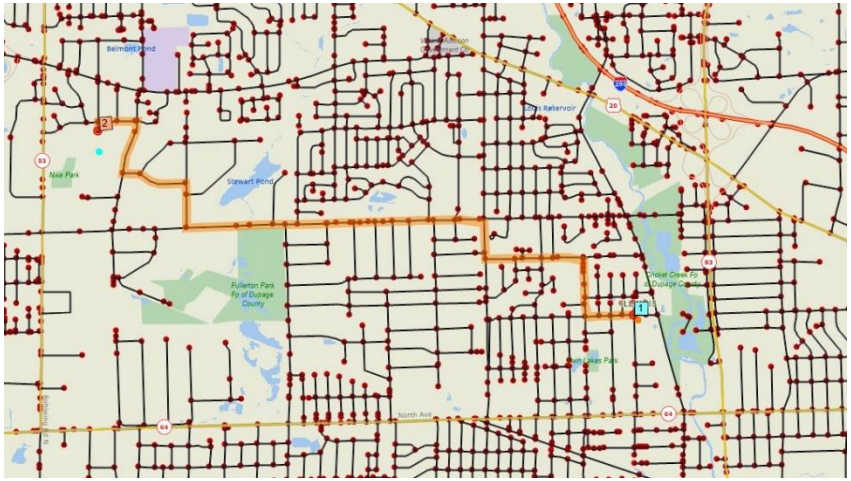


TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Lombard 4080 (Suburban) Tour





TECHNICAL ACCOMPLISHMENTS AND PROGRESS
Lombard 4080 (Suburban) Tour



TECHNICAL ACCOMPLISHMENTS AND PROGRESS ENERGY ESTIMATES

Tours	Jefferson 2880 (urban) kWh	Jefferson 4440 (urban - CBD) kWh	Lombard 4080 (suburban) kWh
Baseline (diesel truck) Energy (ORNL)	101.4	21.2	566.2
Alternative 1: EV truck	23.6	5.0	132.0
Alternative 1: diesel truck to UPS, EV van	64.4	18.7	122.1
Alternative 2: EV truck to UPS, EV van	15.3	3.2	77.2
Alternative 3: diesel truck to locker, quadcopter	46.4	14.9	65.6
Alternative 4: EV truck to locker, quadcopter	13.5	3.9	40.2
Alternative 5: diesel truck to locker, hexacopter	89.1	21.3	456.0
Alternative 6: EV truck to locker, hexacopter	56.3	10.3	430.6
Alternative 7: diesel truck to UPS, Nuro	58.1	17.8	74.4
Alternative 8: EV truck to UPS, Nuro	16.2	4.5	37.7
Alternative 9: diesel truck to locker	42.8	14.3	33.0
Alternative 10: EV truck to locker	10.0	3.3	7.7

= Highest

= Lowest

TECHNICAL ACCOMPLISHMENTS AND PROGRESS PUBLICATIONS AND PRESENTATIONS

FY 18 Presentations:

1. ORNL Postdoctoral Association Research Symposium, August 2017
2. Urban Dynamics Institute, December 2017
3. Women in STEM Symposium, University of Tennessee, March 2018
4. Energy, Utility, and Environment Conference, March 2018
5. Urban Dynamics Institute, March 2018
6. American Association of Geographers, April 2018
7. ORNL Earth Day, April 2018
8. American Planning Association, April 2018
9. AutoCarta Conference and Symposium, May 2018

TECHNICAL ACCOMPLISHMENTS AND PROGRESS PUBLICATIONS AND PRESENTATIONS

FY 19 Publications:

1) Moore, Amy M. Optimization of Intra-City Freight Movement with New Delivery Methods. Transportation Research Board Annual Meeting Compendium of Papers. (January 2019).

2) Hou, Y., Moore, A., Duran, A., Walkowicz, K., and Smith, D. A Hybrid Tour-Based Model for Energy Analysis of Multi-Modal Intra-City Freight: A Case Study of Autonomous Electric Vehicles. Transportation Research Board Annual Meeting Compendium of Papers. (January 2019).

FY 19 Presentations:

1. Florida Atlantic University ITE Seminar, March 2019
2. Tennessee Environmental Conference, March 2019
3. Transportation Research Board 98th Annual Meeting, January 2019
4. Transportation Research Board 98th Annual Meeting, January 2019
5. Transportation Research Board 98th Annual Meeting, January 2019
6. Transportation Research Board 98th Annual Meeting, January 2019
7. Institute of Electrical and Electronics Engineers 21st International Conference on Intelligent Transportation Systems, November 2018
8. University of Tennessee Transportation Engineering Seminar, October 2018

RESPONSES TO PREVIOUS YEARS' REVIEWERS' COMMENTS

Additional drone considerations?

– We addressed this by using hexacoptor, quadcoptor, and ground vehicles for the scenarios

Additional data from other parcel delivery companies?

– We've attempted to address this by obtaining additional data from UPS

– Our alternative response for addressing this is by estimating delivery demand from all parcel delivery companies based on market share assumptions

Future Work described seems vague and high-level?

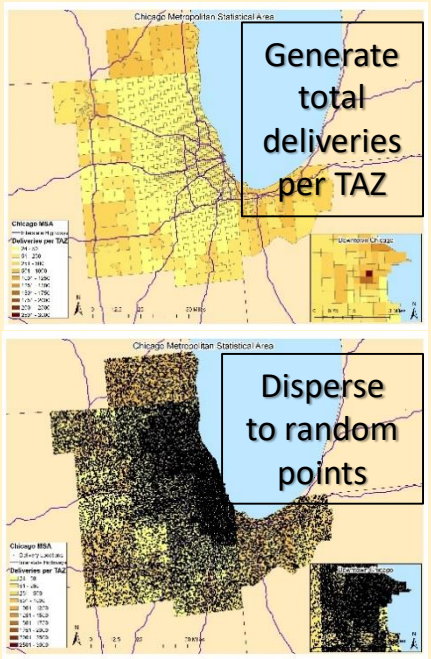
– We addressed this by our on-going integration with ANL and POLARIS

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

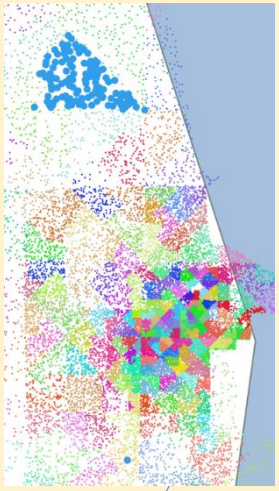
- The intra-city freight tour modeling work is primarily a collaboration between ORNL and INL
- INL performed all of the drone testing
- ANL provided guidance and baseline energy estimates from POLARIS
- NREL provided access to IHS database (vehicle ownership data)
- LBNL provided data on e-commerce and consumer shopping preferences
- UPS provided truck movement data and parcel characteristics data for Columbus, Ohio as part of the FY 17 and FY 18 work, which was the basis for model development in Chicago
- The Chicago Metropolitan Agency for Planning (CMAP) provided Census-level data for model development

Parcel Delivery O/D to POLARIS (MM Task 3.1 -> MM Task 4.1)

DELIVERY ESTIMATION → TOUR CREATION → MM Task 4.1/POLARIS → SCENARIO GENERATION/ MM 3.1

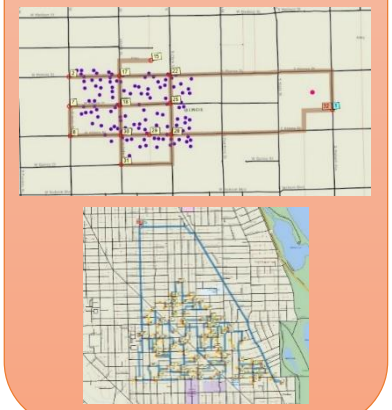


Base year



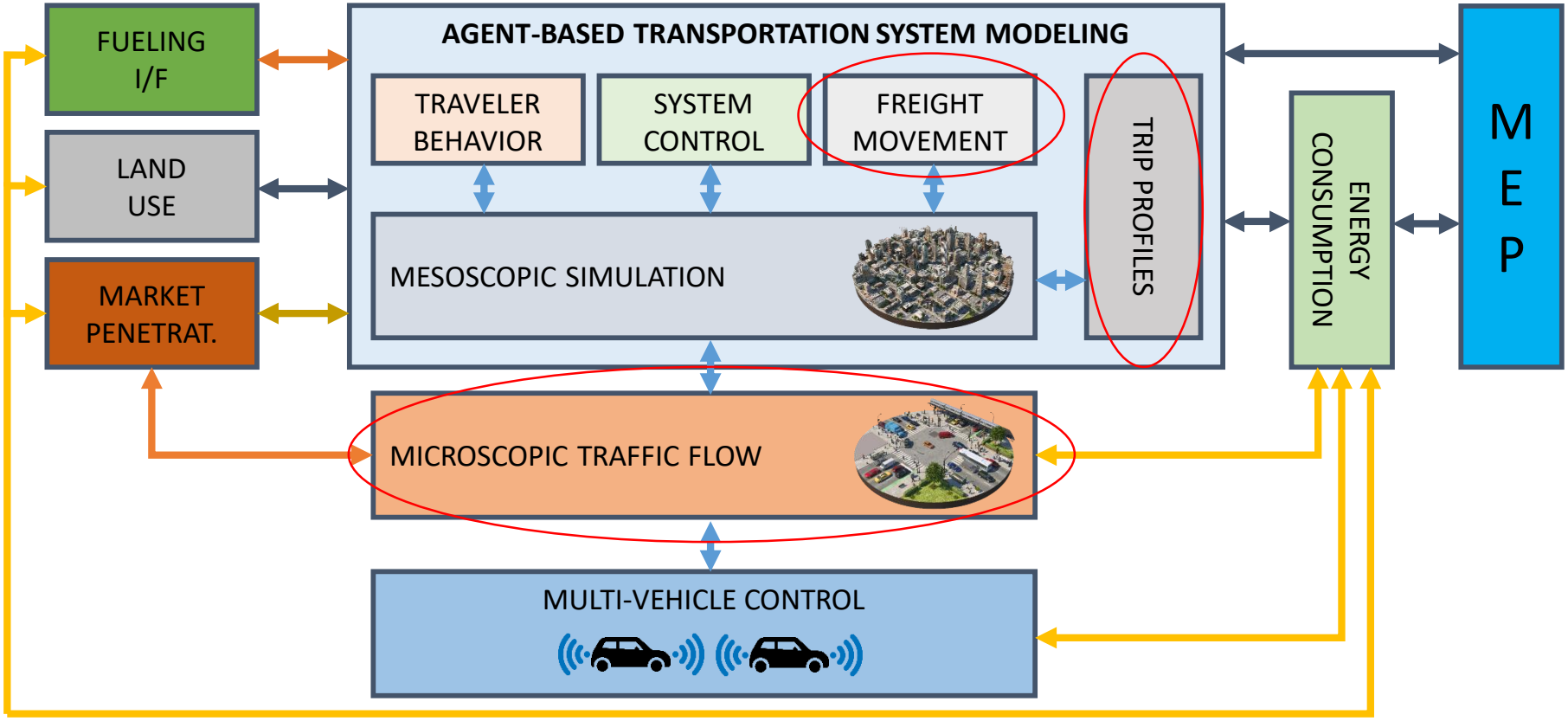
Future-year tours
Vehicle agents
Tours routed in POLARIS

Alternative scenario generation using new modes in TransCAD



SMART WORKFLOW

END-TO-END MODELING WORKFLOW



REMAINING CHALLENGES AND BARRIERS

- **Data needs**
  - Parcel delivery data for Chicago
  - Market share data for all Chicago parcel delivery companies
  - Alternative mode performance data for refined energy calculations
  - Advanced data on energy use for new alternatives (such as Autonomous ground systems)

- **Alternative applicability**
  - Look at impacts based on availability and use
  - Impacts of freight on passenger congestion

PROPOSED FUTURE RESEARCH

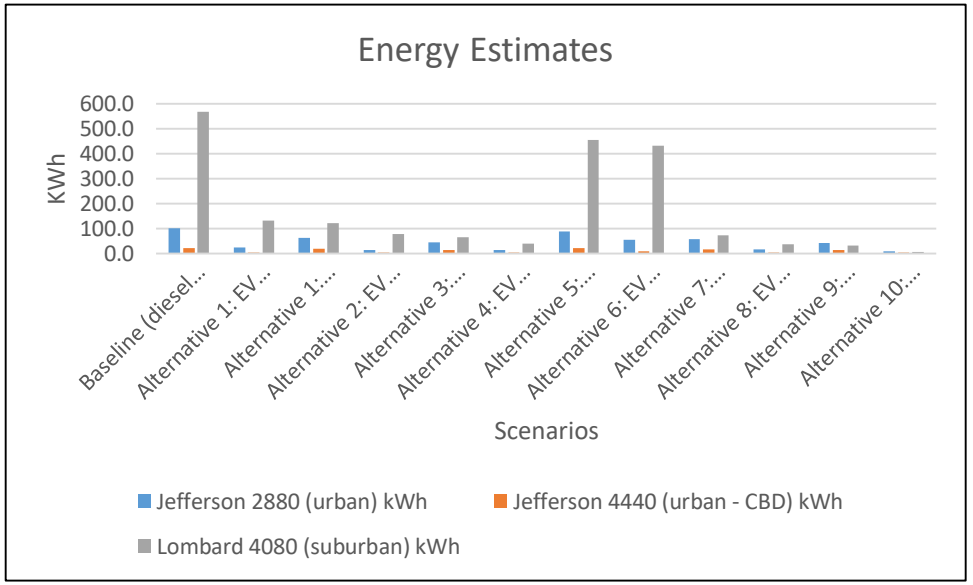
- Ongoing
  - FY19: Refine delivery demand estimation model using UPS data for Chicago
  - FY19: Replicate methodology for developing dataset to represent delivery locations (for all parcel delivery companies in Chicago)
  - FY19: Replicate alternative scenario generation (batch processing for entire Chicago MSA)
  - FY19: Obtain energy estimates to compare with baseline estimates in POLARIS
- Proposed
  - Working with industry for deployment issues
  - Further testing impact of autonomy and new technology
  - Looking at interplay of systems and performance
  - Evaluate further the impacts of Business to Business based on changes

SUMMARY SLIDE

- **Relevance:** Evaluate energy-saving potential of new intra-city freight delivery methods
- **Approach:** Investigate Technologies, Gather Delivery Data, Model Scenarios, Expand to Regional Impacts
- **Collaborations:** ORNL, INL, ANL, NREL, UPS, CMAP

- **Technical Accomplishments:**
  - Estimated O-D pairs, provided to ANL to be used as input for POLARIS to represent displaced passenger vehicle shopping trips
  - Evaluated alternative freight delivery modes

- **Future Work:**
  - Estimate all parcel delivery demand (existing and future) for Chicago MSA
  - Further assist ANL with development of freight agents within POLARIS to better understand the effects of e-commerce on the transportation network



SUMMARY SLIDE

Key Take-Aways:

- Intra-city delivery needs will only increase
- Issues continue to increase with demand
- Many options have potential to provide solutions to transportation issues
- Further evaluation needed to fully characterize issues and solutions
- “Right-Size” solutions to enhance energy use
- Using alternative delivery points and multiple modes appear to be more effective on reducing energy usage

QUESTIONS?